CHAPTER 3

PRIMARY ELECTRICAL DISTRIBUTION

3-1. General primary electrical distribution

Primary electrical distribution system is defined in this manual to be the electrical system operating above 600 Vac. Secondary distribution system is defined as 600 Vac and below. Without electrical power to operate equipment, provide illumination, etc., site operations would be very difficult or impossible; therefore, correct operation and maintenance of the primary electrical distributions system is essential.

3-2. Substations

Substations control the flow of power into a facility. They are comprised of transformers for stepping down the voltage, high-voltage insulators, and large air/oil circuit breakers capable of interrupting tremendous amounts of current during fault conditions.

a. Transformers. A transformer utilizes electromagnetic (EM) induction between circuits of the same frequency, usually with changed values of voltage and current. Transformers can be classified in various ways, but their basic construction consists of windings, magnetic cores on which windings are coiled, insulation, and any special connections applying to the type of load. Substation transformers can range in size from a garbage can to a small house. Their main purpose is to transform alternating voltage and current from one level to another. At the power plant the voltage is brought up to a higher voltage for efficiency in transmitting the power to the end user. At the end user's locale the voltage is brought down to a level that is suitable for operations.

(1) The basic design of a transformer consists of electrical coils wrapped around an iron or steel core. By controlling the number of windings, or tapping into the windings, various levels of voltage change can occur. Nameplate information for each transformer will help in identifying the primary coil and the secondary coil ratings, in addition to how the transformer is configured.

(2) Transformers rated above 500 kVA are classed as power transformers. Transformers rated at 500 kVA or less are classed as distribution transformers, as they usually have low tension windings of less than 600 volts.

(3) American National Standards Institute/Institute of Electrical and Electronic Engineers (ANSI/IEEE) C57.12.80, Standard Terminology for Power and Distribution Transformers (1992), identifies several classes of insulation systems for power and distribution transformers. Insulation classifications are based upon the insulation’s temperature rating and the method of cooling needed to remove the heat from the transformer. The core and the coils of dry type transformers are in a gaseous or dry-compound insulating material. The core and the coils of liquid-immersed transformers are contained in an insulating liquid. Flammable mineral oil insulation is the most frequently used liquid. Various less flammable liquids are used to meet National Electrical Code (NEC) code requirements. Only flammable and less flammable liquids are acceptable on military installations. Non-flammable insulated liquids, though available, are not considered environmentally acceptable. Polychlorinated biphenyl (PCB) insulated transformers should be removed to meet Environmental Protection Agency (EPA) requirements. Replacement of liquid-filled transformers in or near buildings must take into account the latest applicable

NEC code restrictions, which might require an existing installation to be modified or a different type of insulating medium to be provided.

(4) All electrical component applications must meet the Electrical Electronic Enclosure Classifications (NEMA Standard 250 for their purposes). An outdoor transformer should be constructed with weather-resistant construction, suitable for service without additional protection from the weather. Industry standards also classify transformers as indoor units, which must be protected from the weather. A pole type transformer is an outdoor transformer that is suitable for mounting on a pole or a similar structure. A pad-mounted transformer is a unitized or compartmental type transformer, with enclosed compartments for medium-voltage and low-voltage cables entering from below, and is mounted on a pad.

(5) Transformers can maintain an acceptable voltage ratio of about a two percent voltage drop from zero to rated output in most cases. Most distribution transformers and smaller power transformers have tapped windings, which permit adjusting the output voltage to broaden the range of primary voltage inputs. The transformer will have a manual tap changer, which can be operated if the transformer is de-energized. However, on substations which serve varying loads, such as pumping facilities, or on large installations with long primary feeder lines, taps may not provide sufficient voltage regulation and other means are necessary.

(6) An automatic load tap changing (LTC) feature installed on a transformer provides automatic tap changing under load, and normally varies the voltage to plus or minus ten percent of the system's rated voltage by changing tap connections using a motor-driven, tap-changing switch.

(7) Sometimes voltage regulation is needed and the system transformers do not include the LTC feature. Voltage regulators are used to supply the control for the variations in load. A voltage regulator needs similar servicing to that required for a power transformer. A step-voltage regulator operates on the same principal as the LTC mechanism. An induction voltage regulator has a series winding and a shunt winding, and uses a motor to rotate the shunt winding to either add to (boost) or subtract from (buck) the series winding voltage. The action provided is dependent upon the voltage induced in the series winding and the respective polarities of each winding (that is, the respective instantaneous directions of currents entering the primary and leaving the secondary terminals during most of each half cycle). The switching mechanism in most new voltage regulators is practically maintenance free, but many of the older units require considerable servicing. The manufacturer's recommendations should be followed for all maintenance and servicing requirements.

b. Insulators. The function of an insulator is to support a conductor or conducting device safely. An insulator, being of a non-conductive material, physically and electrically separates the supported item from any grounded or energized conductors or devices. Insulators are composed of porcelain, glass, fiberglass, or a composite compound. Maintenance is necessary to preserve their insulating ability that can be degraded by contamination or other damaging actions. Most insulator damage will result from gun shots; lightning, surge, or contamination flashovers; and wind damage. Defective insulators can also cause visible corona or interference voltage propagation.

c. Bushings. A bushing is an insulating structure that provides a conducting path though its center while its body isolates contact to the support structure. A bushing has a provision for mounting on a barrier (conducting or otherwise). The bushing insulates the conductor from the barrier and conducts current from one side of the barrier to the other side. The primary function of a bushing is to provide an insulated entrance for an energized conductor into an apparatus tank.

d. Instrument transformers. Current and potential (voltage) transformers are used to enable ammeters and wattmeters to monitor power conditions. An instrument transformer is designed to reproduce in its secondary circuit (in a definite and known proportion) the current or voltage of its primary circuit with the phase relations and waveform substantially preserved.

(1) A current transformer is a constant-current transformer that reduces line currents into values suitable for standard measuring devices such as ammeters and wattmeters and standard protective and control devices. It also isolates these devices from line voltages. The primary winding is connected in series with the circuit carrying the line current, or as a window type arrangement linked magnetically with the line conductor which eliminates the need for an integral primary winding.

(2) A potential transformer is basically a conventional constant-voltage transformer with primary and secondary windings on a common core connected in shunt or parallel to the power supply circuit to be measured or controlled. The secondary winding insulates devices from the power circuit.

e. Switches. Substation switches can be operated manually or power operated. Insulation for the voltage and current interrupting level may be provided by operating the contacts in air, oil, vacuum, or in a sulfur hexafluoride (SF_6) gas medium. Switches are classified by their ability to interrupt load.

(1) A disconnecting switch is a device used to open, close, or change the connections in a circuit or system. It has no interrupting rating and is used for isolating equipment only after the circuit has been opened by some other means. Two special types are as follows.

(2) A grounding switch is a switch used to connect a circuit or piece of equipment to ground.

(3) A horn-gap switch is a switch provided with arcing horns to aid in dispersing any arc that may occur when the switch is operated. This combination is sometimes referred to as an air-break switch. It should not be operated except to interrupt the charging current of a short length of line, or the magnetizing current of a de-energized transformer. Oil switches should always be considered as disconnect switches, unless the switch nameplate indicates a fault closing rating suitable for the system's maximum available fault.

(4) Interrupter switches have specific capabilities for switching one or more of the following type of loads: 0.8 minimum lagging power factor load, parallel or loop load, transformer magnetizing load, line charging load, cable charging load, and capacitor bank load. Follow the manufacturer's instructions when operating interrupter switches.

(5) Non-fault closing type switches are equipped with means of interrupting current, at rated voltage, not in excess of the switch's continuous rated current. Interrupter switches, which do not have a fault-closing rating, may be damaged if inadvertently closed on a short circuit. Appropriate precautions should be taken to avoid danger to the operator.

(6) Fault closing type switches are equipped with means for interrupting current, at rated voltage, in excess of the switch's continuous rated current. Interrupter switches with fault-closing ratings are intended to provide adequate personnel protection, when closing into a short circuit, up to the asymmetrical fault-closing rating of the switch and when applied in accordance with the manufacturer's recommendation.

f. Bus structures. A bus structure is an assembly of bus conductors with associated connection joints and insulating supports. It can have bare or insulated conductors. A busway is a grounded metal enclosure, containing factory-mounted bare or insulated conductors, that are usually copper or aluminum bars, rods, or tubes. Each serves as a common connection between two or more circuits.

3-3. Overhead distribution

Overhead electrical distribution at all voltages most often uses open wire construction, although aerial cables of various types are employed to some extent. Poles, towers, and other supporting structures define overhead distribution. When several different voltages are found on these structures the hierarchy is the highest voltage is at the top. Voltages drop as the circuits descend downward.

a. Open wire construction. The basic features of open wire construction are single conductors, insulated supports, and wide separation, with little or no conductor covering on the conductors. The air space around the conductors must be large enough to allow relative conductor movement without a flashover. Open wire construction is mounted on insulators, either as armless or crossarm construction.

b. Armless construction. Armless construction consists of insulators on supporting brackets mounted directly on the pole. When possible, this construction is preferred for use on pole replacements because of its more attractive appearance and lower maintenance cost. Triangular tangent construction is preferred over vertical tangent construction, as it requires the least conductor space and is more economical. Triangular construction is not suitable for configurations that require an overhead ground wire. It is not recommended except for the tangent and minor angle construction.

c. Poles. Poles are constructed of wood, metal, or concrete. Extending out from these structures are crossarms that support the overhead cable. The poles can be self-supporting or may require guys (stranded galvanized wire) or braces to hold the pole in position.

d. Crossarm construction. Unless it conflicts with facility practice, crossarm construction should be phased out whenever possible, but may be necessary where equipment or line installations, utilizing armless construction, would result in excessive pole heights. Facility practice usually matches the local utility company's open wire construction.

e. Overhead cable. Aerial cable has its individual conductors insulated and supported by a messenger (support wire) along its length. The cable is then lashed and clamped to the insulators mounted on the poles or towers.

f. Overvoltage protection. Overhead lines are extremely vulnerable to direct strokes or to induced voltage influences. Underground systems derived from aerial lines may also be affected. Lightning results from the potential difference between clouds or between a cloud and earth. A lightning stroke may be in direct contact with an electric line and equipment. The charged clouds of a passing lightning storm may also cause an electrostatically induced voltage.

(1) The high voltage of a lightning surge, imposed on lines and devices without surge protection, will flash over the insulation in the majority of cases. Where flashover occurs, through air or on insulators, it rarely causes permanent damage, but flashover occurring through the solid insulation on equipment or cable can result in permanent damage.

(2) A surge limiting protective device must limit transient over-voltages or surge voltages that could damage apparatus. The device must bypass the surge to ground and discharge severe surge currents of high magnitude and long duration without injury. The device must continuously withstand the rated power voltage for which it is designed. The device's protective ratio is the maximum surge voltage it will discharge, compared to the maximum crest power voltage it will withstand following discharge. Surge arresters provide the most accepted method of surge limiting protection, since they provide the highest degree of surge elimination. Other methods include shielding lines and equipment from direct lightning strokes; and providing devices designed to divert or change the waveform of the surge, such as protective gaps, surge capacitors, and bypass resistors. A surge arrester is a protective device for limiting surge voltages on equipment by discharging or bypassing surge current. Surge arresters allow only minimal flow of the 60 hertz power current to ground. After the high-frequency lightning surge current has been discharged, a surge arrester, correctly applied, will be capable of repeating its protective function until another surge voltage must be discharged.

(3) Surge arresters used for protection of exterior electrical distribution lines will be either of the metal-oxide or gapped silicon-carbide type. Expulsion type units are no longer used.

3-4. Switchgear

Switchgear is a general term covering switching and interrupting devices that control, meter, and protect the flow of electric power. The component parts include circuit breakers, instrument transformers, transfer switches, voltage regulators, instruments, and protective relays and devices. Switchgear includes associated interconnections and supporting or enclosing structures. The various configurations range in size from a single panel to an assembly of panels and enclosures. The latter is normally constructed into cubicles with a circuit interrupter in one and auxiliary equipment in the others. It is then normally connected to a transformer. Equipment rated up to 1000 volts alternating current (AC) is classed as low voltage. Equipment equal to or greater than 1000 volts but less than 100,000 volts AC is classed as medium voltage.

a. Medium voltage switchgear. Major elements of medium voltage switchgear are circuit breakers, potential transformers, current transformers, and control circuits. Construction of circuit breakers employed in the two types of switchgear and the methods to accomplish breaker tripping are the primary differences. The service entrance conductors and main bus are typical heavy-duty conductors rated for use between 601 volts AC and 38,000 volts AC, as required.

b. Circuit interrupters. These interrupters can be air circuit breakers, arc interrupters, vacuum circuit breakers, or oil circuit breakers. Some can be removed from their cubicle while others must be checked in place.

c. Fuses. High voltage fuses can provide current or non-current limiting features. Their use can be dictated by the manufacturer or end user requirements. Available types are sand filled, liquid filled, or vented expulsion type.

d. Lightning (surge) arrestors. Arrestors are provided to pass high energy surges directly to ground thereby protecting the other electrical equipment downstream.

e. Protective relays. Protective relays provide quick isolation of power systems under fault conditions. They can detect overcurrent, overvoltage, under-voltage, current balance, current flow, frequency, and impedance.

f. Alarms. Various alarms available are transformer over temperature, high or low pressure, circuit breaker trip, ground fault, or switchgear over temperature.

g. Interlocks. Interlocks are provided for personnel safety to prevent operation of equipment in an unsafe manner.

3-5. Circuit breakers

Circuit breakers are a special form of switching mechanism, which can open and close circuits under both normal and abnormal conditions. When they are electrically controlled, they can be operated locally or remotely, or by both modes. Oil, SF_6, vacuum, and air are the insulating mediums used on most installations. The selection of the insulation generally relates to the voltage level being interrupted. Usually the air circuit breakers have draw-out construction. This feature permits removal of an individual breaker from the switchgear enclosure for inspection or maintenance without de-energizing the main bus.

a. High-voltage breakers. Until recently most installed high-voltage circuit breakers were of the oil-insulated type. However, the use of SF_6 gas insulated units is increasing as these take less space for a given voltage and are environmentally preferable.

b. Medium-voltage breakers. Newly installed medium-voltage switchgear utilizes vacuum construction which provides a considerable space saving over air-magnetic units.